HL-LHC related fast Timing R&D in RD50/51

Sebastian White, CERN/Princeton

LHCb weekly, Sept. 6, 2016

aim of fast sensor development: mitigate effects of pileup
-> "Hermetic Timing Layer"

~20 picosecond track resolution
-> time slice 170ps rms of IR

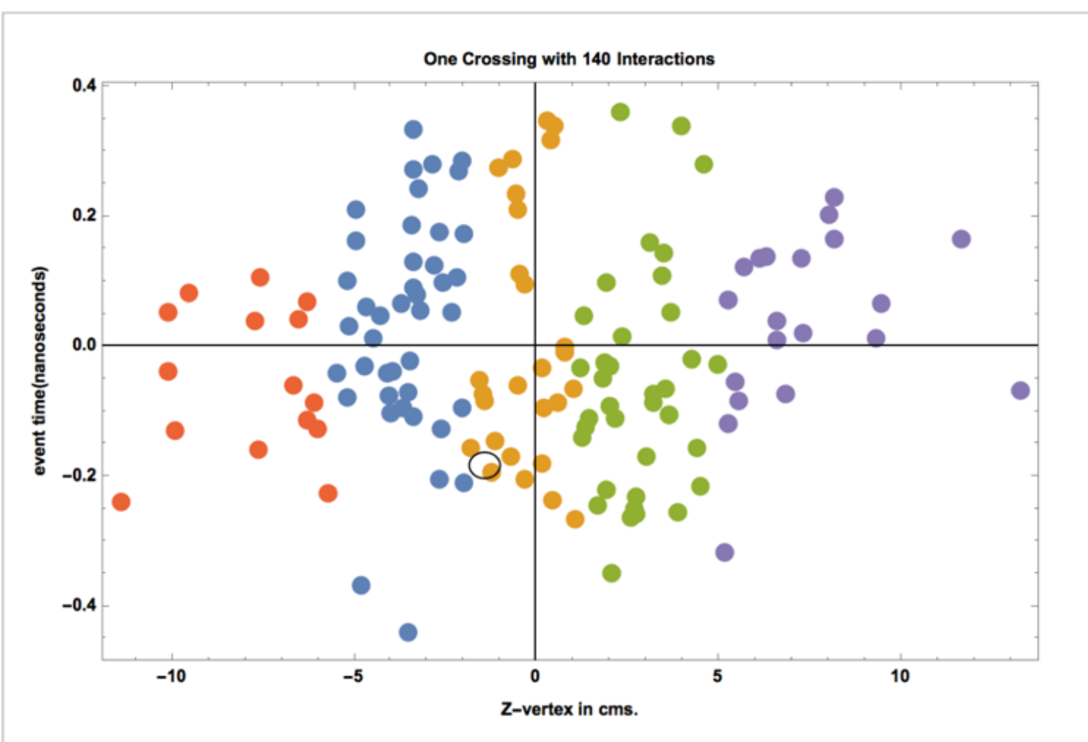
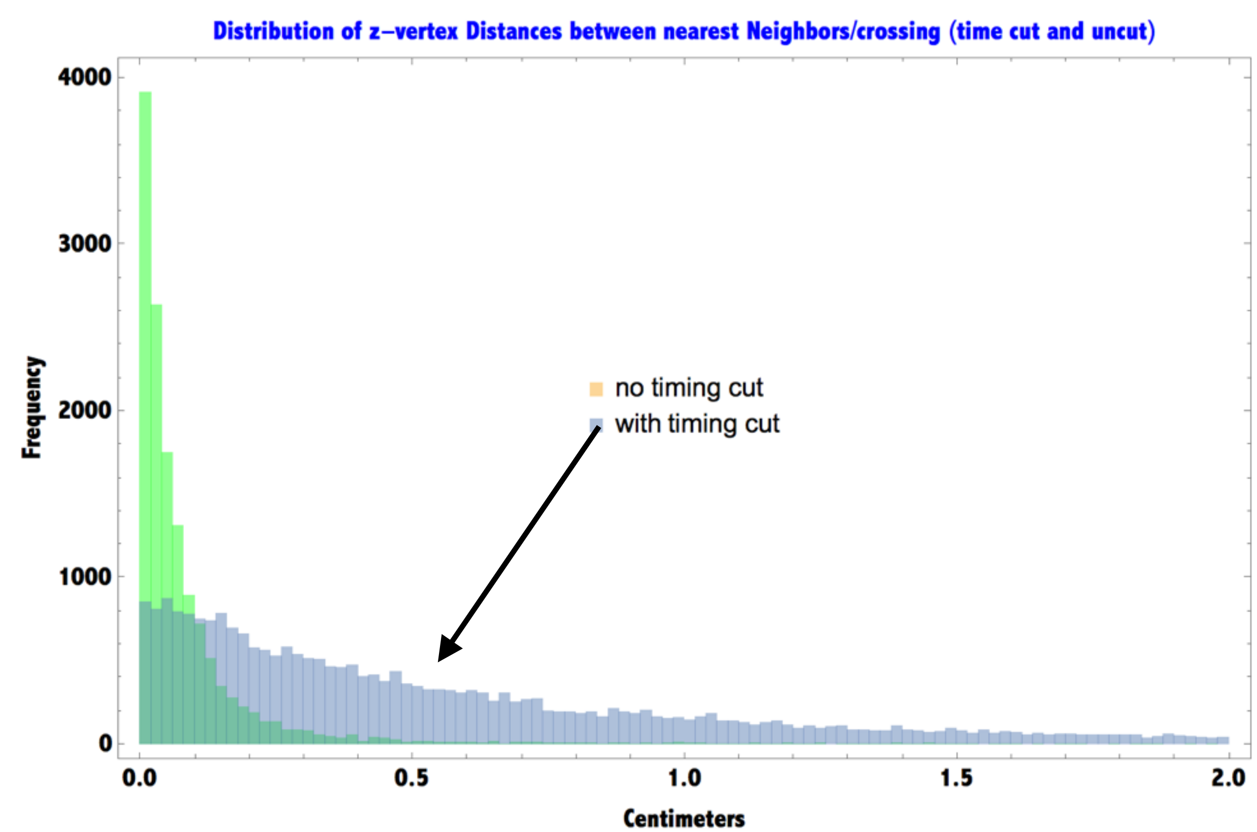


Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

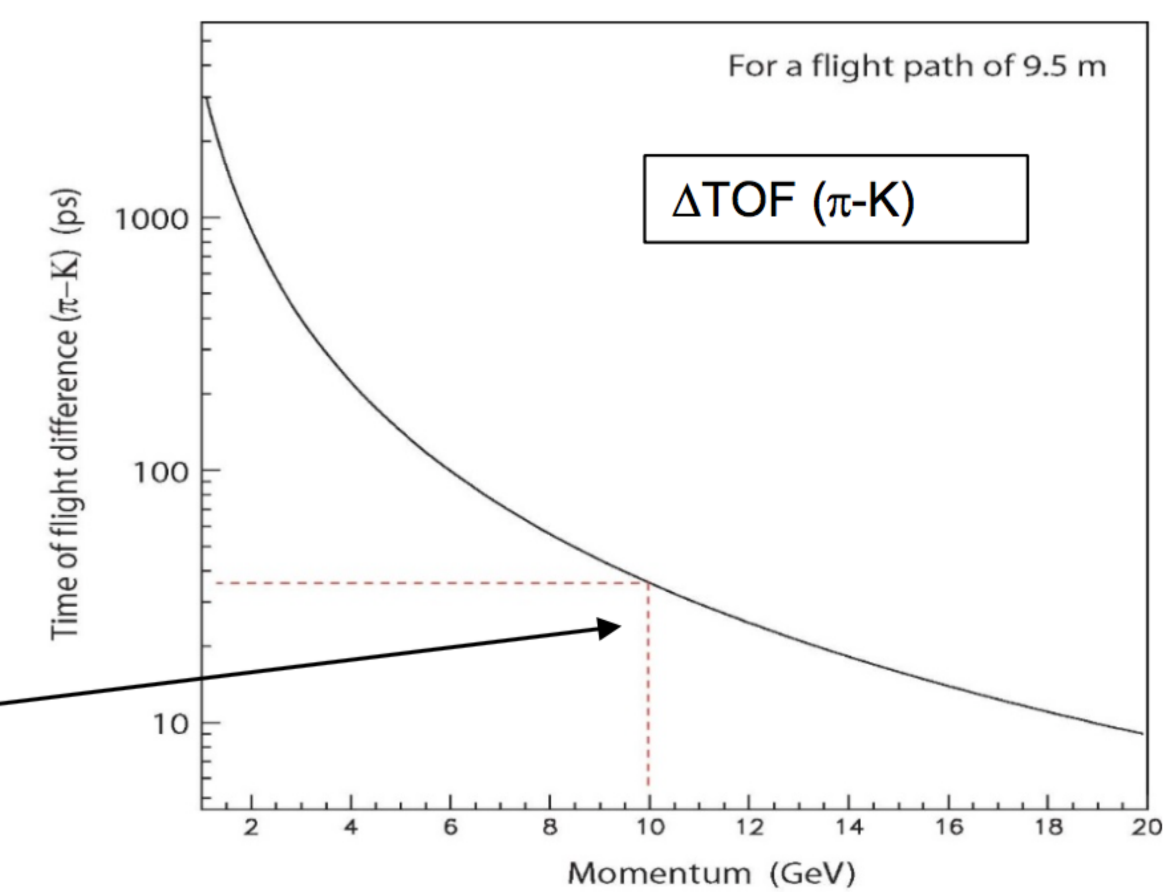


- HL-LHC physics simulation in CMS developing case for background reduction using Calorimeter timing and the significant improvement w. t0 measurement from hermetic timing layer.
- Benefits to track reconstruction more straightforward.
- dt resolution clear from IR time spread->~20 picoseconds
- cell size determined by occupancy->~1 cm^2, down to ~0.25 at eta=3
- different from “4-D tracking for future experiments” see eg. Sadrozinski:

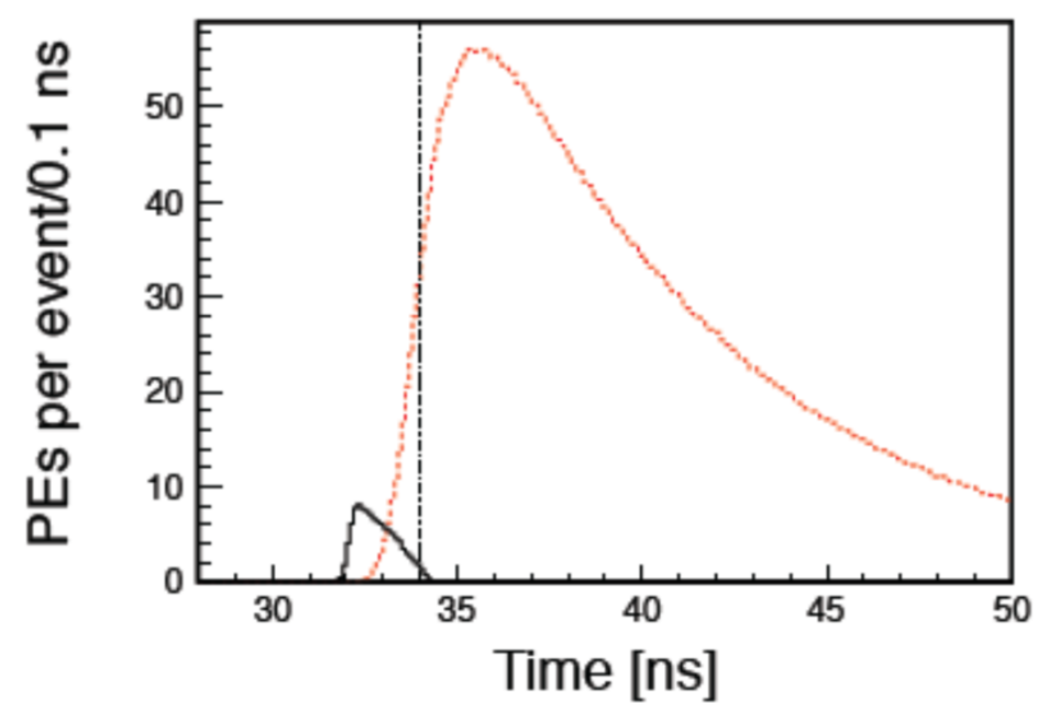
https://indico.cern.ch/event/228876/contributions/1539115/attachments/378013/525816/Sadrozinski_UFSD_HSTD9.pdf

Possible spin-off in other applications requiring large coverage timing layers:

PID a la TORCH&ALICE



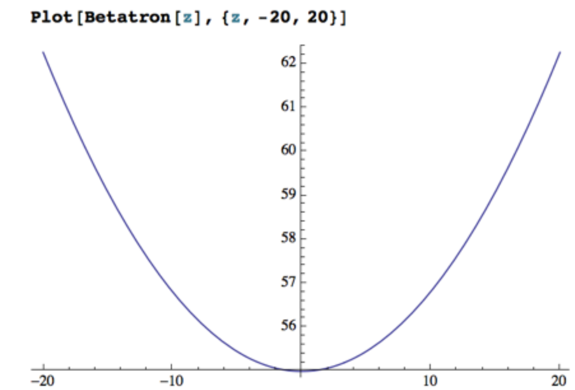
C+Scint. photon detection in LBN&NDBD, J. Klein-Penn



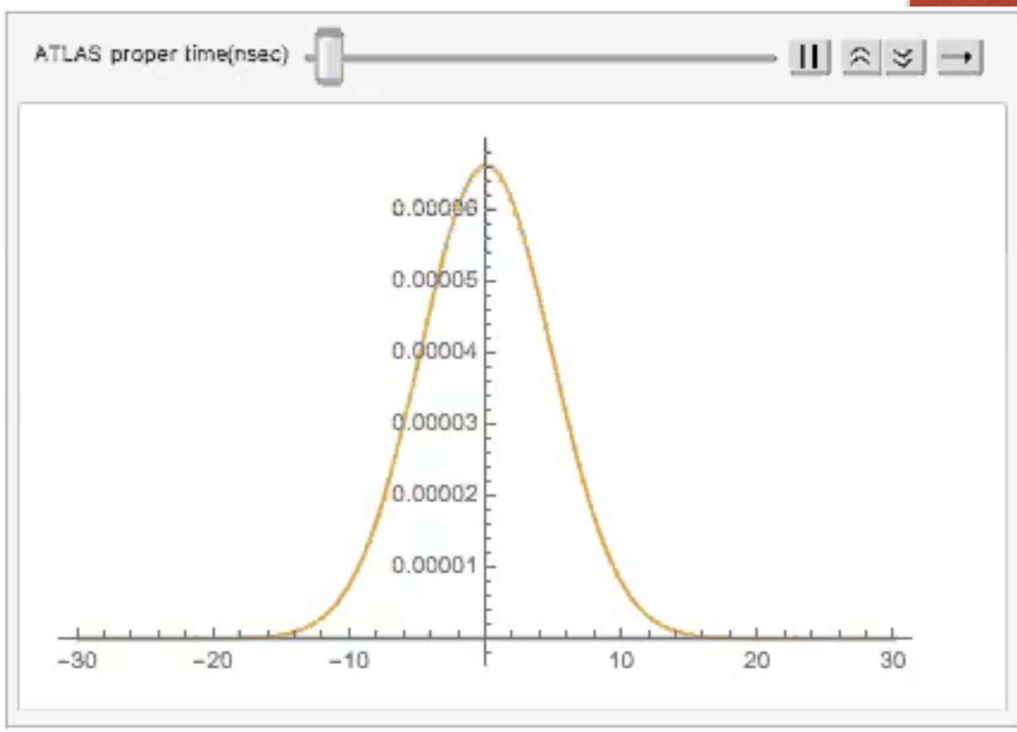
0.1 ns time resolution e.g.

visualize pileup in LHC

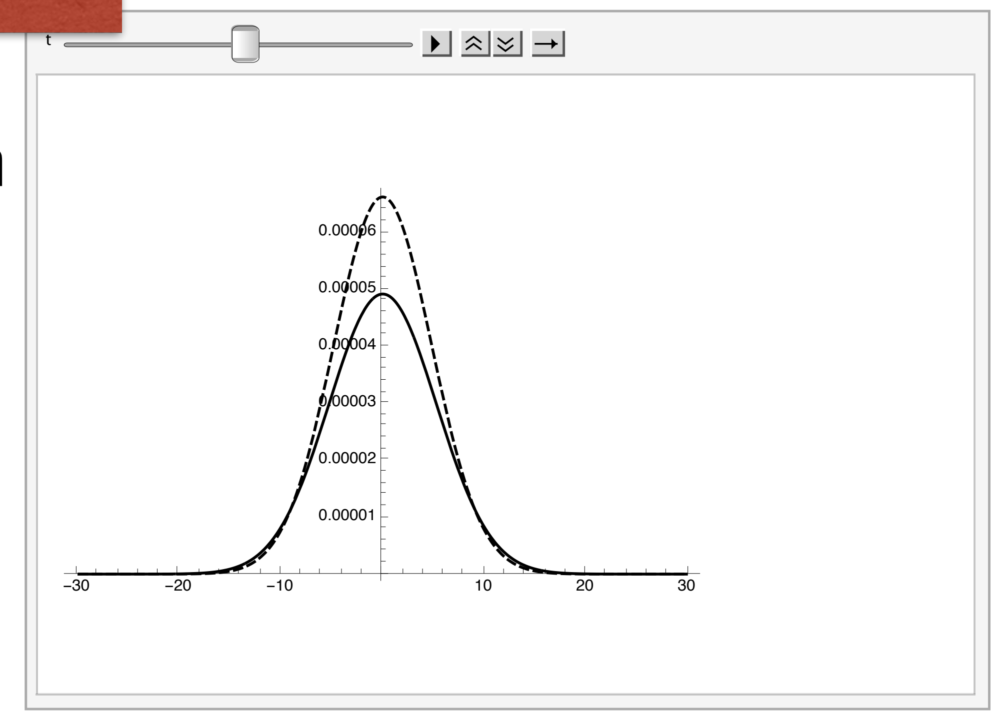
Basic Fomulae for determining the Luminosity function L (z, t) = L (z)*L (t). The beam cross section is given by $\sigma_{x,y}{}^2 = \epsilon_{x,y}\,\beta(z)/(6\pi\gamma)$, where ϵ is the transverse emittance of the beam, the betatron amplitude function, $\beta(z)$, is the one for a drift since there are no focusing elements in the region of interest and γ is the usual relativistic factor. Since the luminosity is $\sim I_1\, I_2 /(\ \sigma_x\, \sigma_y\ )$, it is weighted by $1/\beta$. We use units of centimeters and nanoseconds throughout.

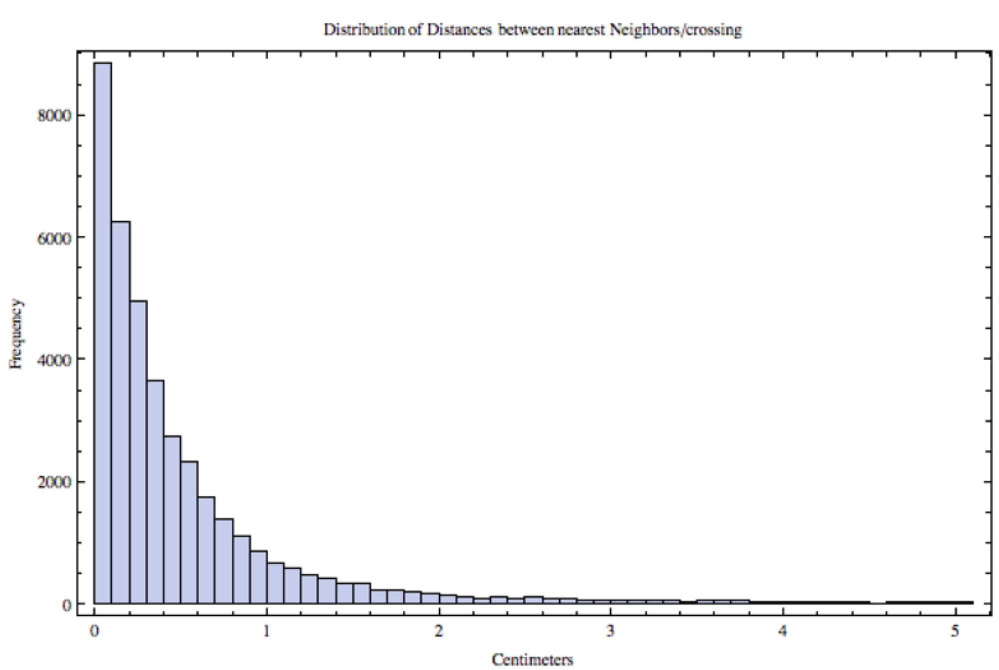


Luminous Region snapshots at t1, t2



->Z_{vertex} distibution time invariant

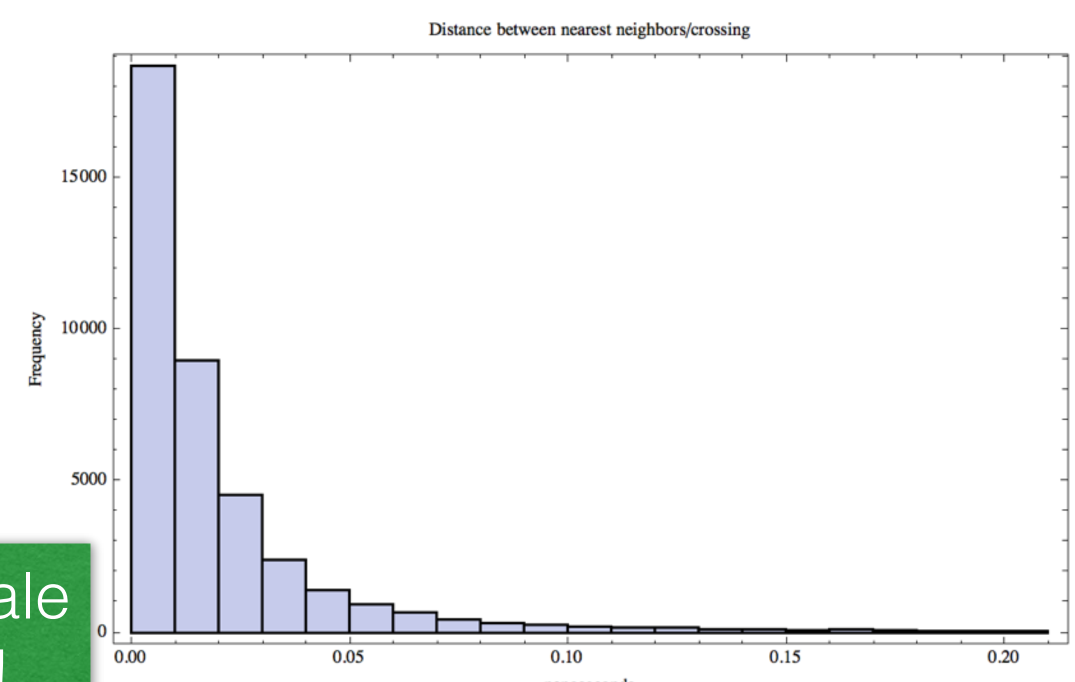




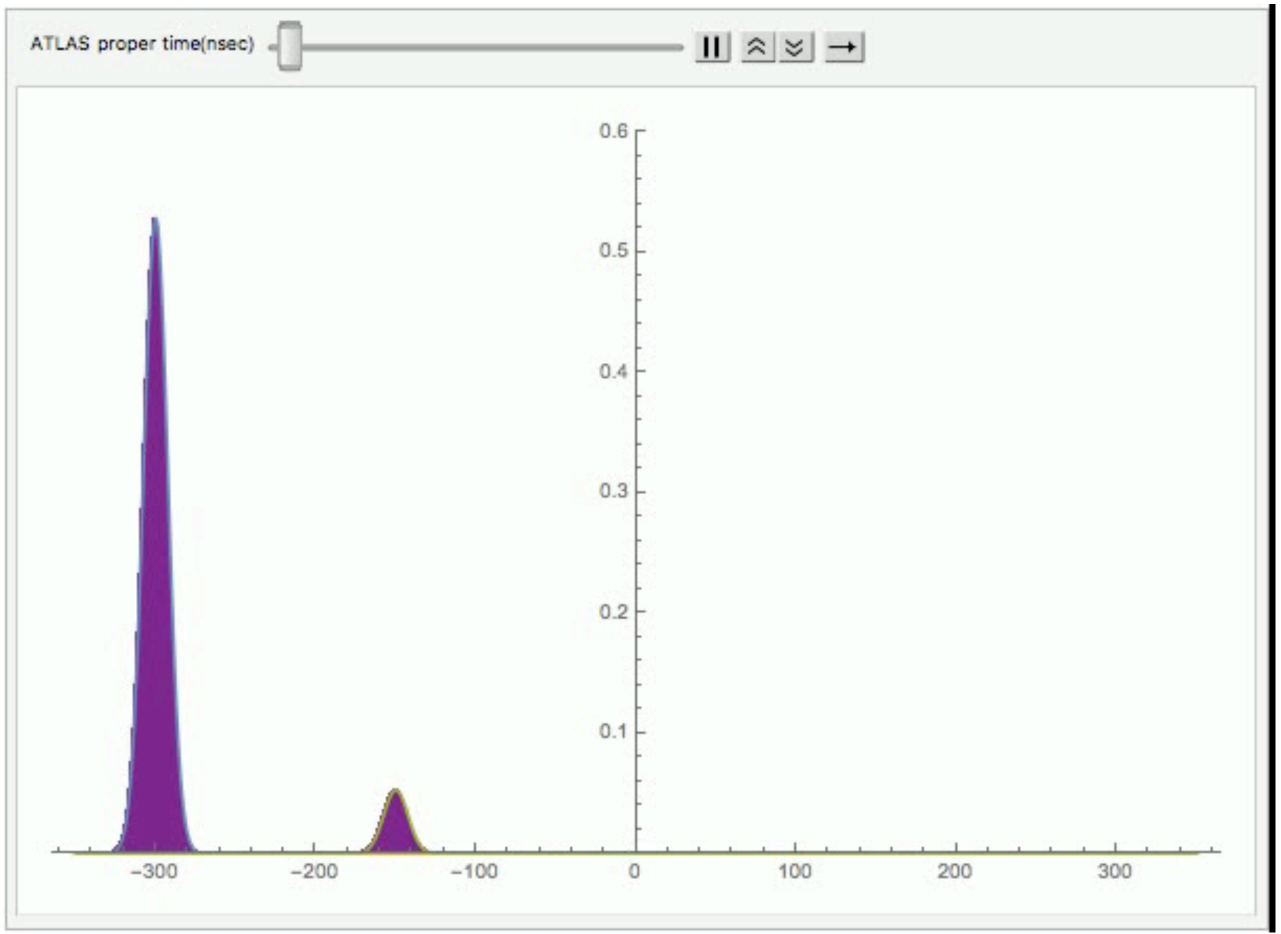
Nearest Neighbor distances

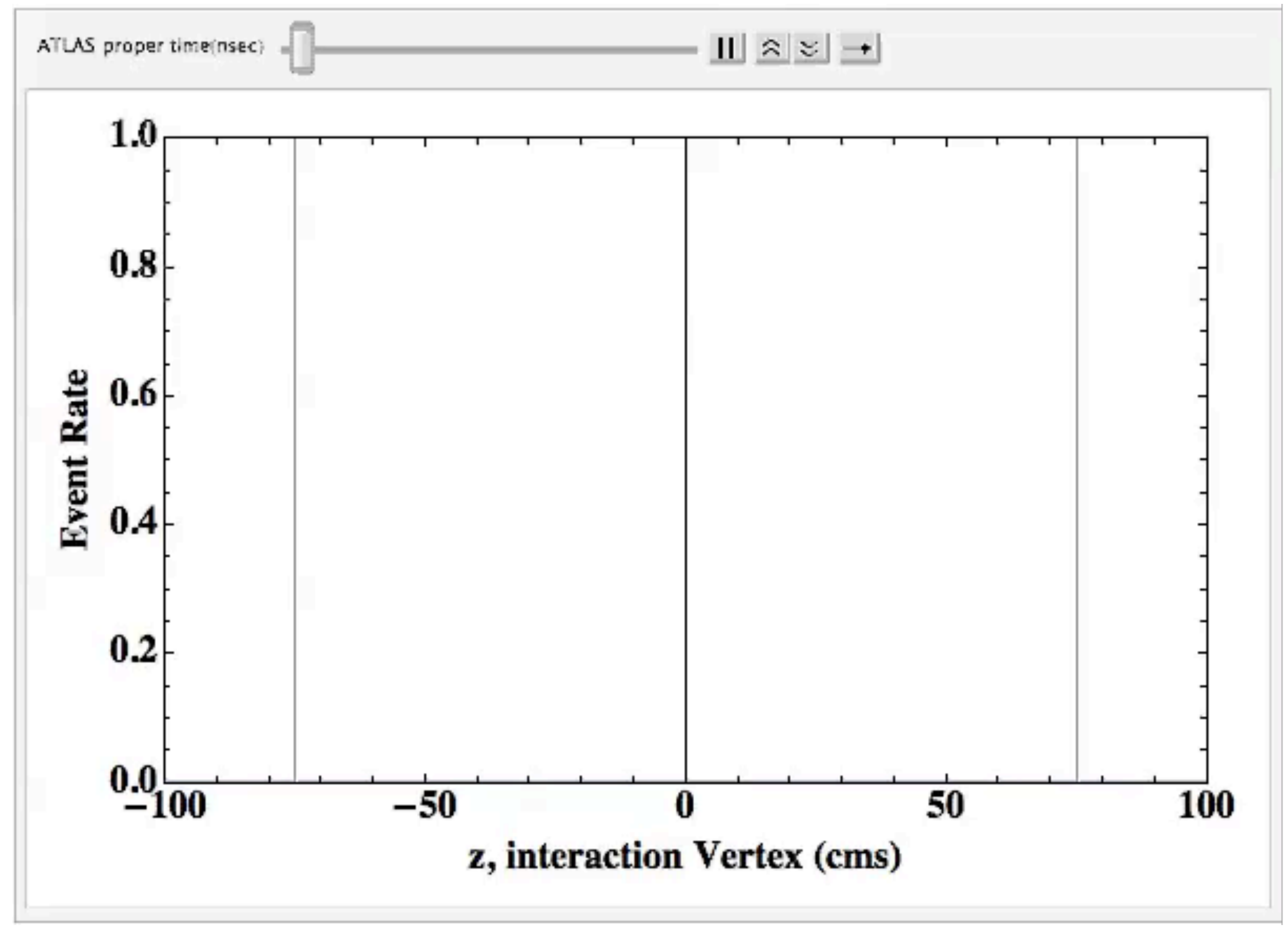
->exponentially distributed

challenging timescale 5 nsec->10 psec!



Start from Historical example:Satellites(LHC,2010)





In early LHC running (2010)observed satellite bunches from 200MHz acceleration rf.

Beata taskforce asked if any detectors sensitive enough to characterize them at level of ~10^{-3}

{today they are a tool for scrubbing}

Today's presentation is a follow-up from CERN detector seminar (Sept. 2015):

https://indico.cern.ch/event/439571/

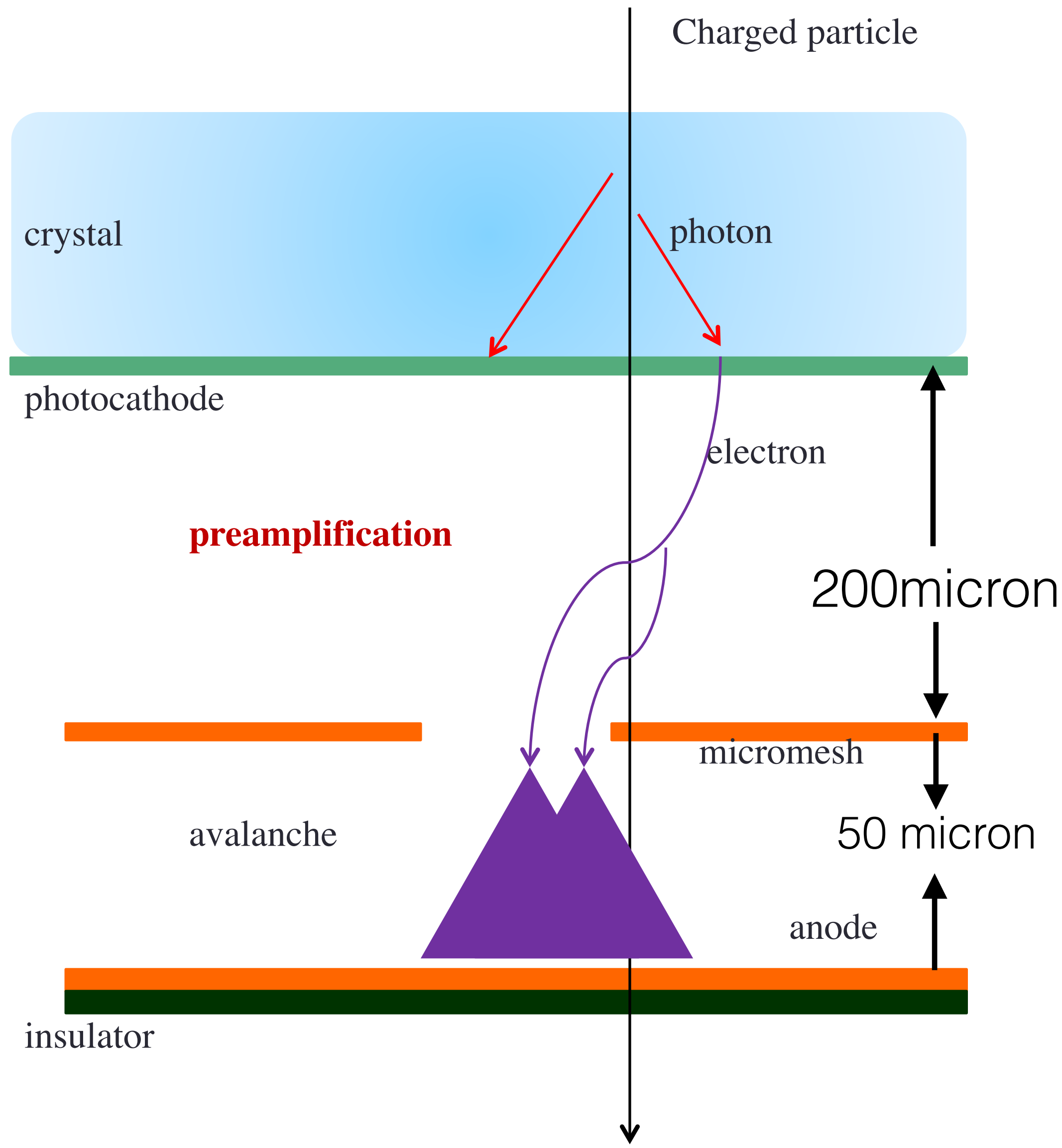
- over the past year we have gone from proof of principle using laser models for MIP timing to beam tests w. 150 GeV muons.
- 2 technologies exploiting speed of micropattern sensors w. internal gain
  - **RD50 capacitive readout Deep Depleted Avalanche Diodes (aka HyperFastSilicon)**

    SSD CERN, Princeton, Delhi, USTC(+RMD+U.Penn)
  - **RD51 PICOSEC project Micromegas coupled to MgF2 Cherenkov radiator+transparent photocathode**

    CEA (Saclay), GDD CERN, Princeton University, Thessaloniki University, USTC (Hefei)
- Significant simulation effort in both technologies. see eg. M. Moll RD50 collar mtg. June 2016
- both technologies tested within RD51 testbeam campaign (June, Aug., Sept)
- here I give a first look at data quality from this campaign
- excellent tracking (~40 micron) give detailed mapping of large area sensor performance

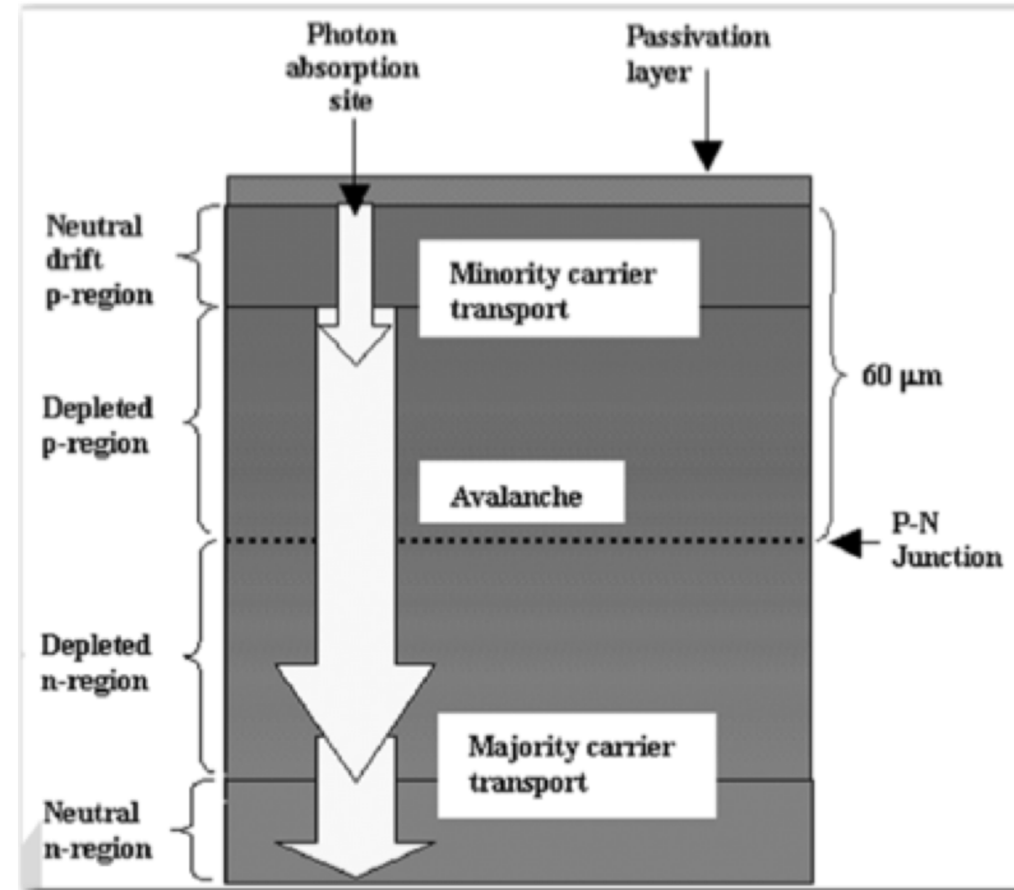
Issues ahead of this past TB campaign:

MPGD:

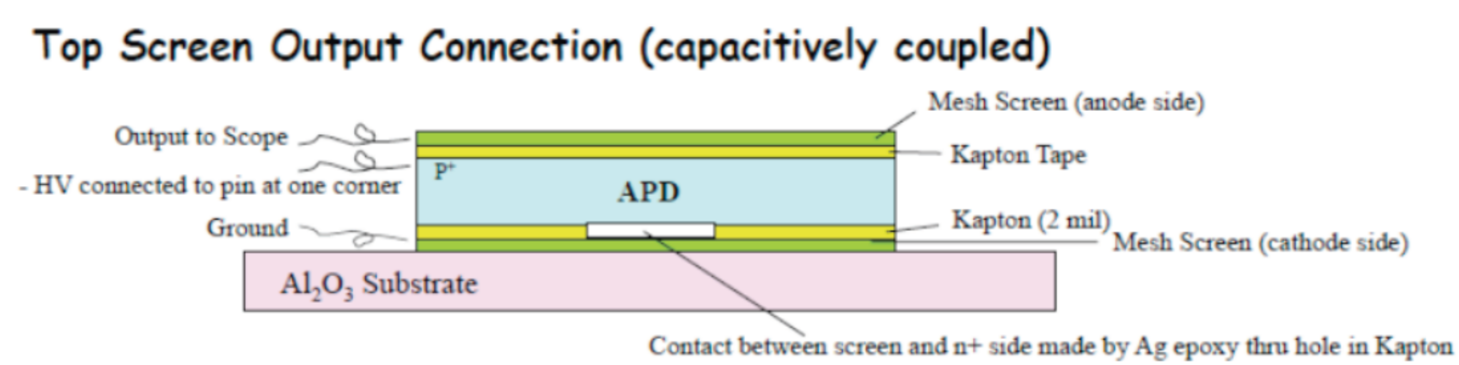


eliminates effect of stochastic energy deposition(Landau)
diffusion limit to time jitter (Gas choice)
robustness of photocathode
(or secondary emitter)

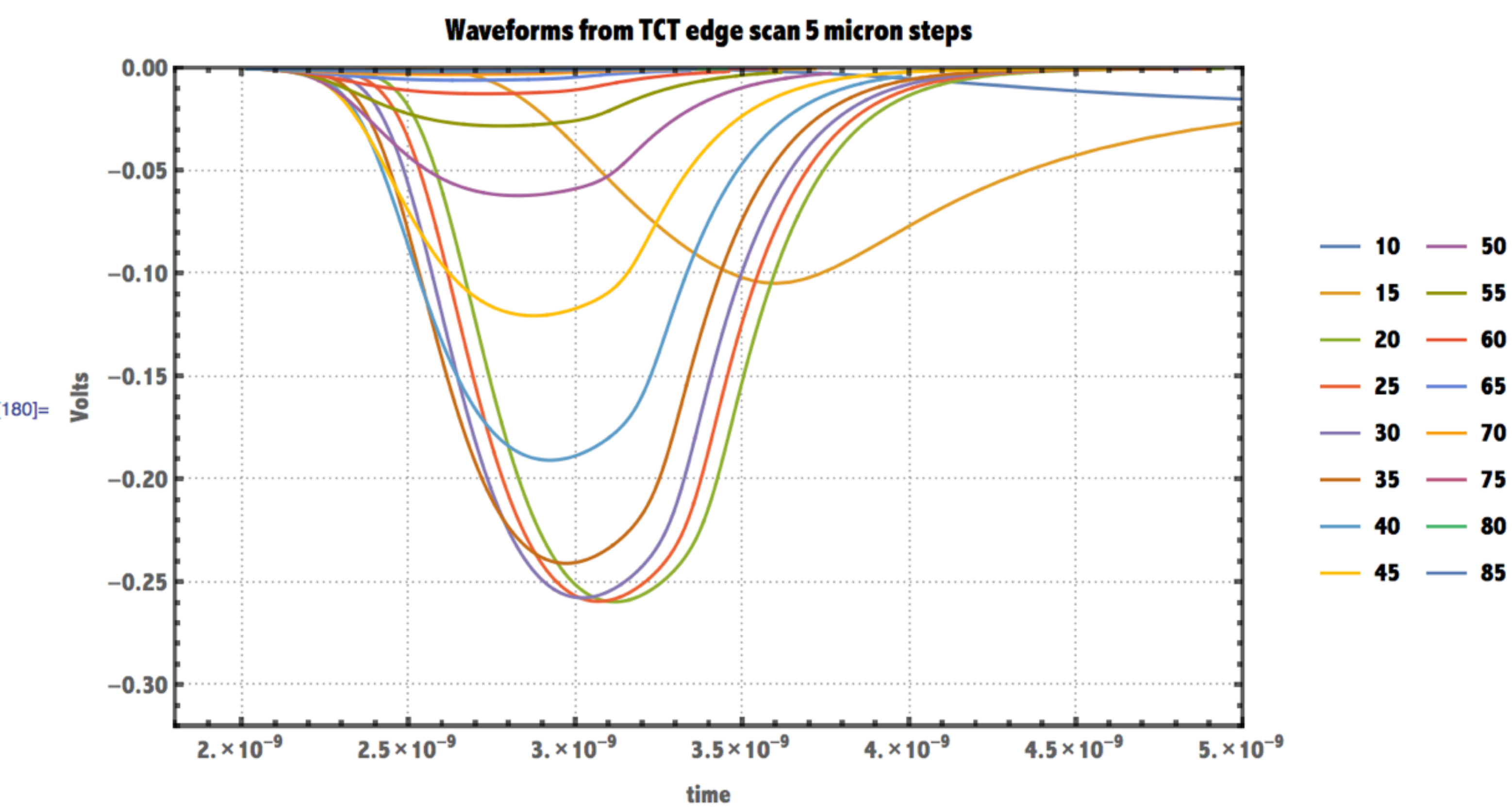
DD-AD(HyperFastSilicon)

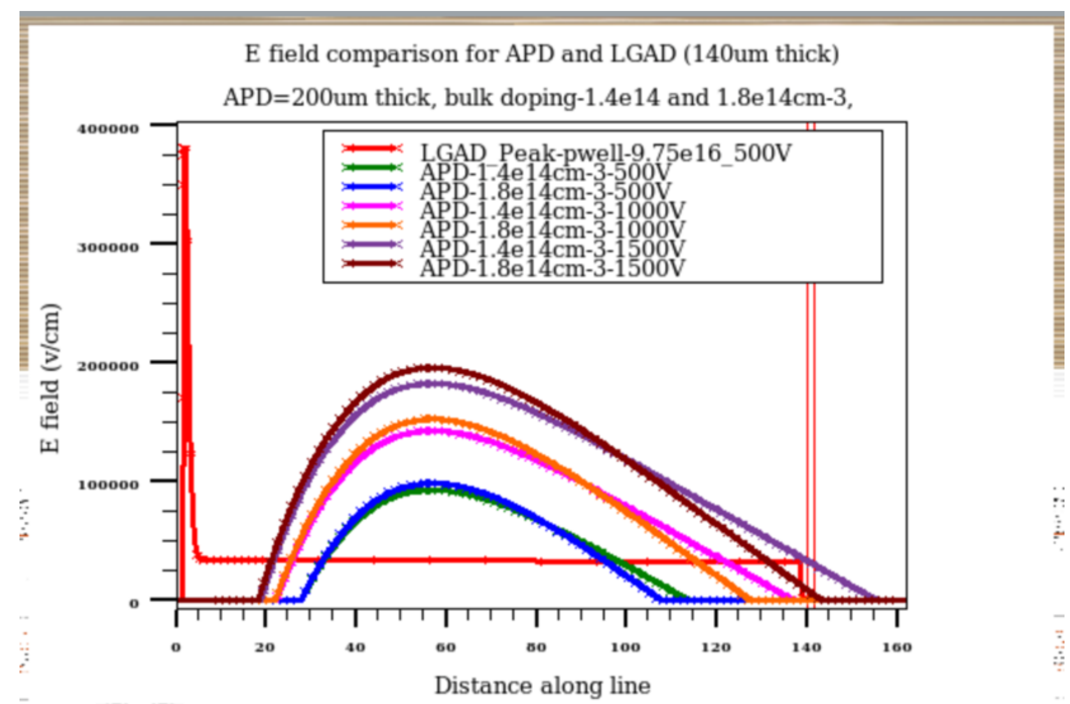


front end and interconnects
rad hardness (so far 0.9 10^{14}p)
optimize structure/bias/algorithm for Landau



Issues for Deep Depleted Avalanche Diodes

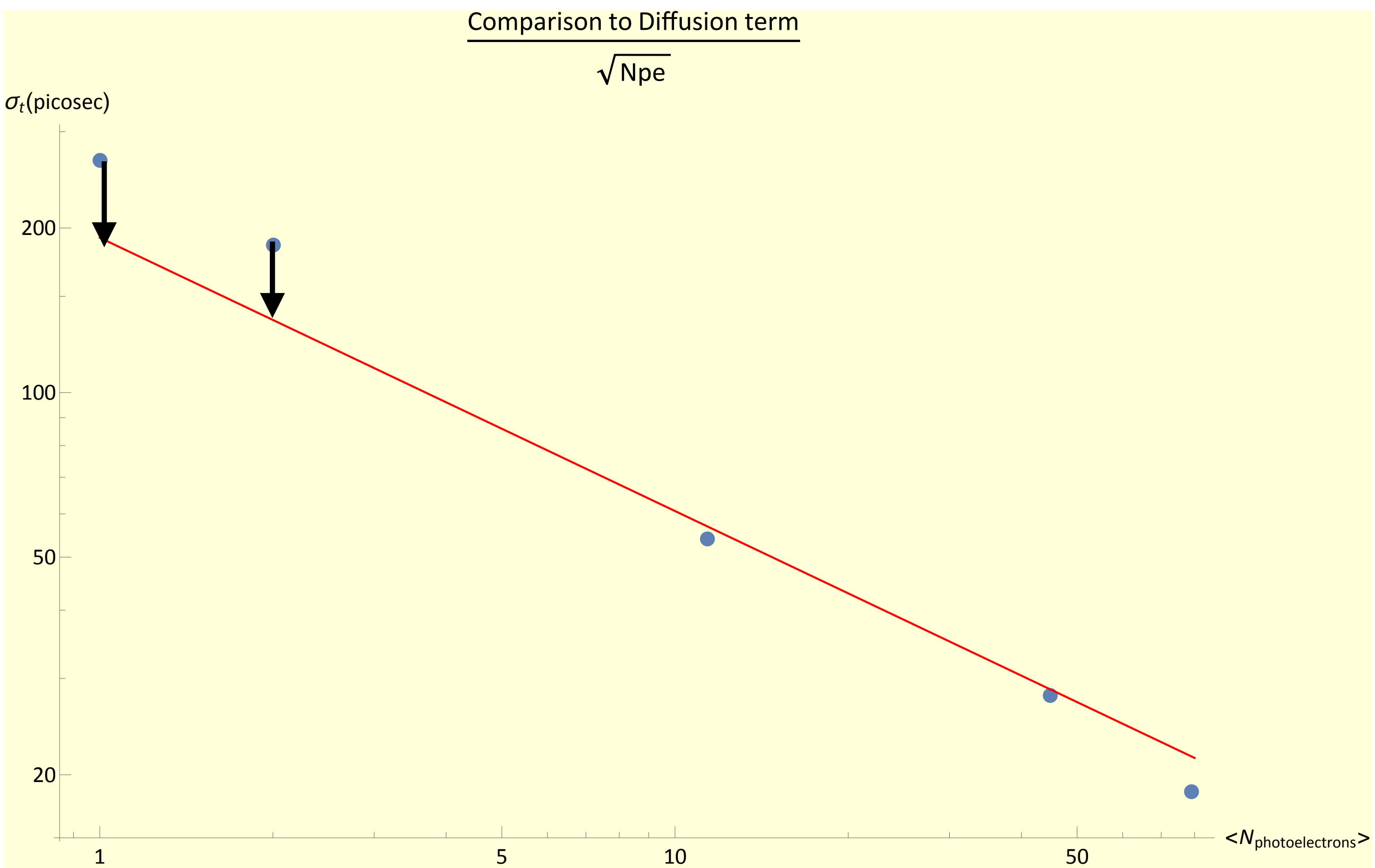




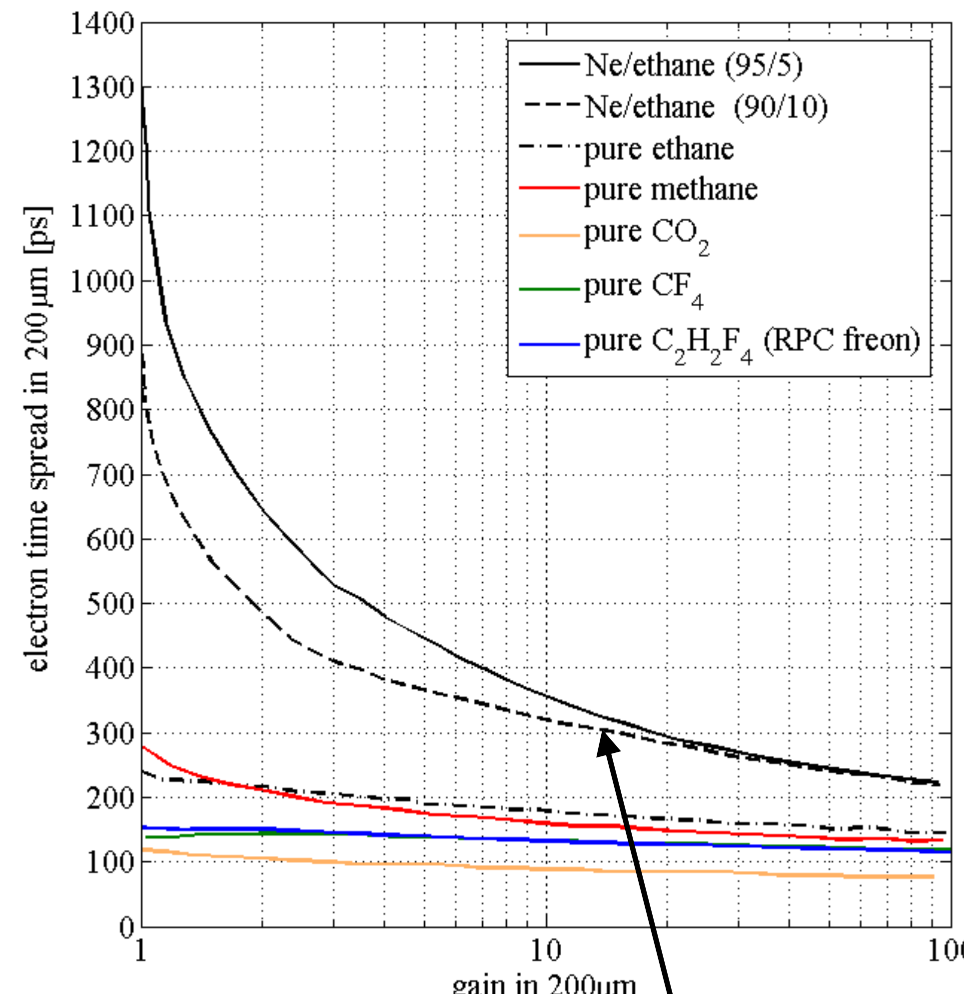
1- continued front end and packaging development
2- understand through simulation and beam the contribution of Landau/Vavilov to time jitter

MPGD: reducing dominant detector physics (longit. diffusion)

2015 proof of Principle laser, NeEthane



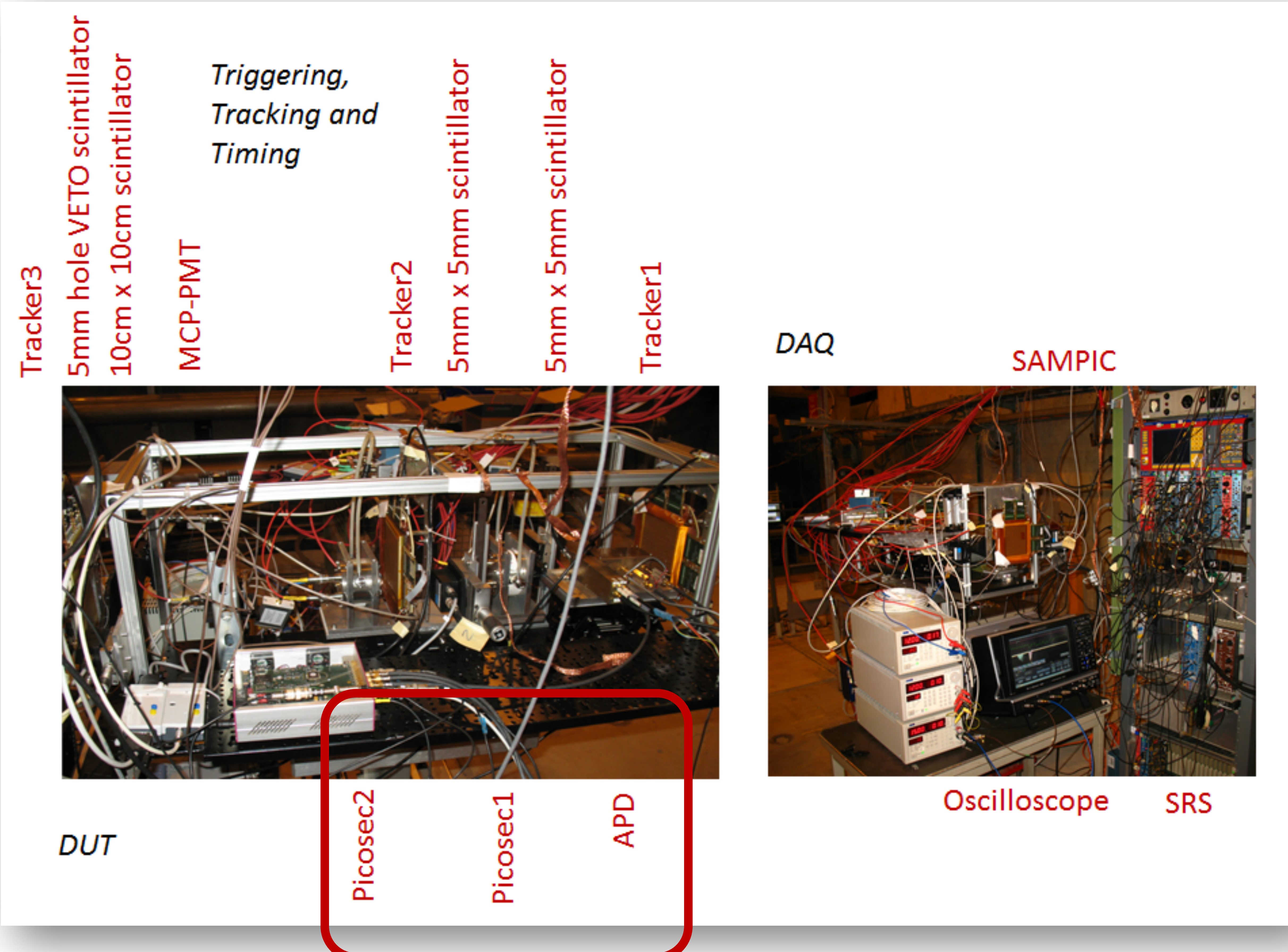
but clearly there could be better choices:



A factor of 3 in Single electron time spread=> few photoelectron regime

2015 operating point

Both technologies tested together in RD51 testbeam(H4)

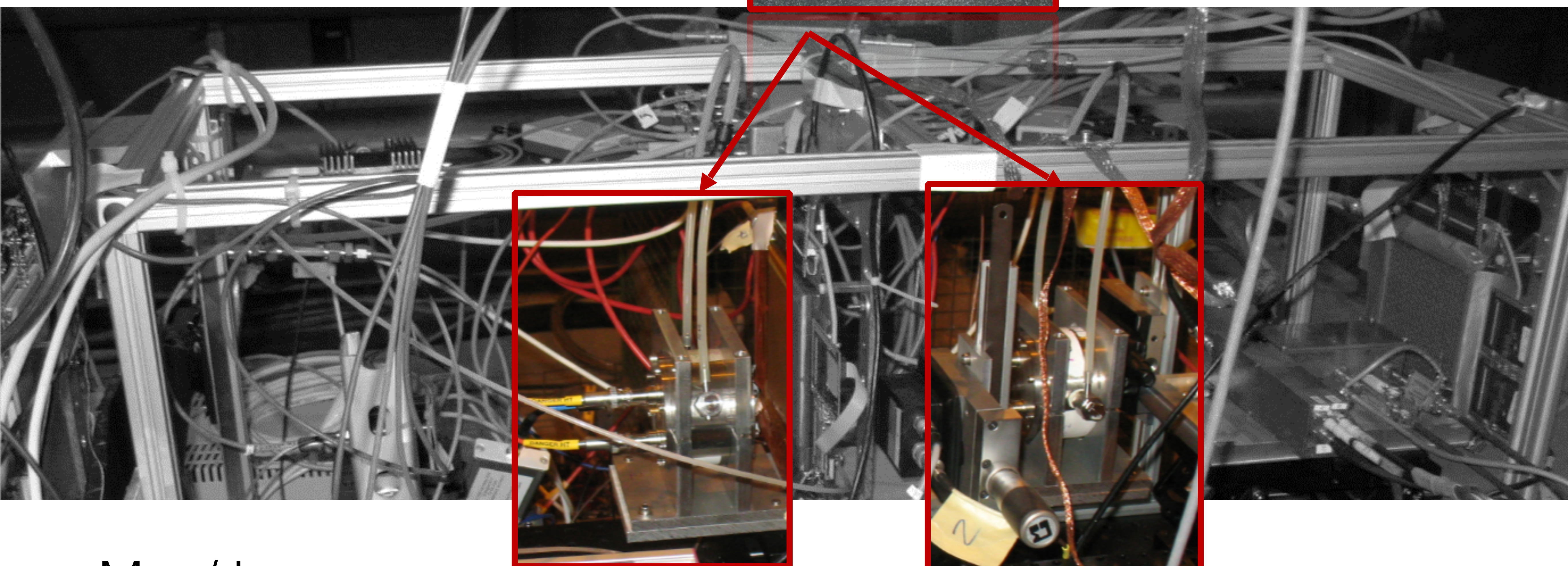


Photocathodes (from Saclay):

1. CsI
2. Al

Radiator: MgF_2 (3mm for CsI, 5m for Al)

Remarkable work done in Saclay for the photocathodes evaporation (Mariam Kebbiri)



May/June

Measurements Performed:

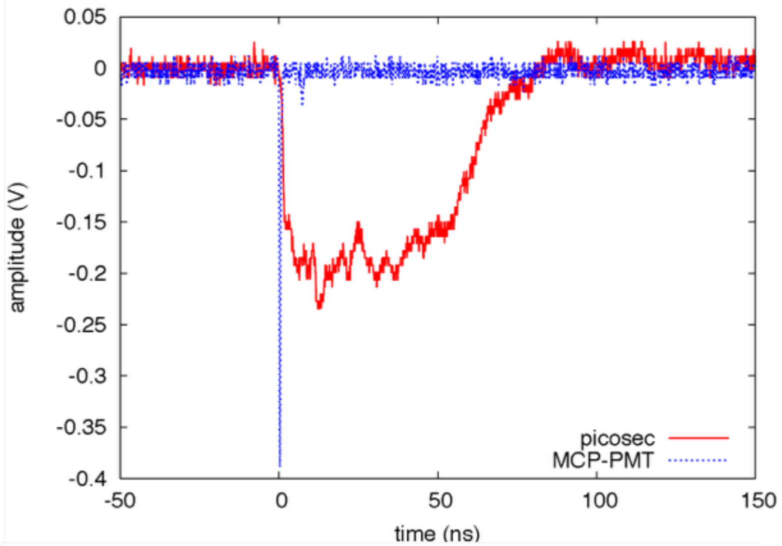
1. CsI and Ne-CF_4-C_2H_6 80-10-10 (Sealed)
2. CsI and Al in Ne-CH_4 95-5 (Sealed)
3. CsI in Pure CO_2 (Sealed)
4. Al in Pure CO_2 (Flushed)

Thanks to the Saclay colleagues Philippe Legou and Olivier Maillard that made a great job on improving the internal cabling, signal routing and grounding

Thanks to the COMPASS colleagues (Yann Bedfer et al.) for providing us some help with the gas

- very professional setup with months of preparation
- several other RD51 technologies (besides PICOSEC) tested

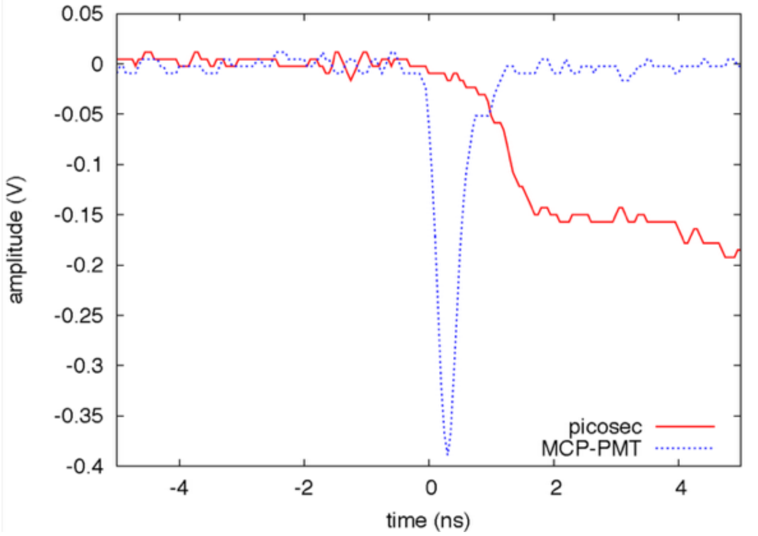
First run (->end May). Preliminary results shown by F. Resnati @ICHEP



in Ne-CF4-C2H6 we reached…

- Time resolution < 100ps
- nphe > 5
- Efficiency.. Practically 100%

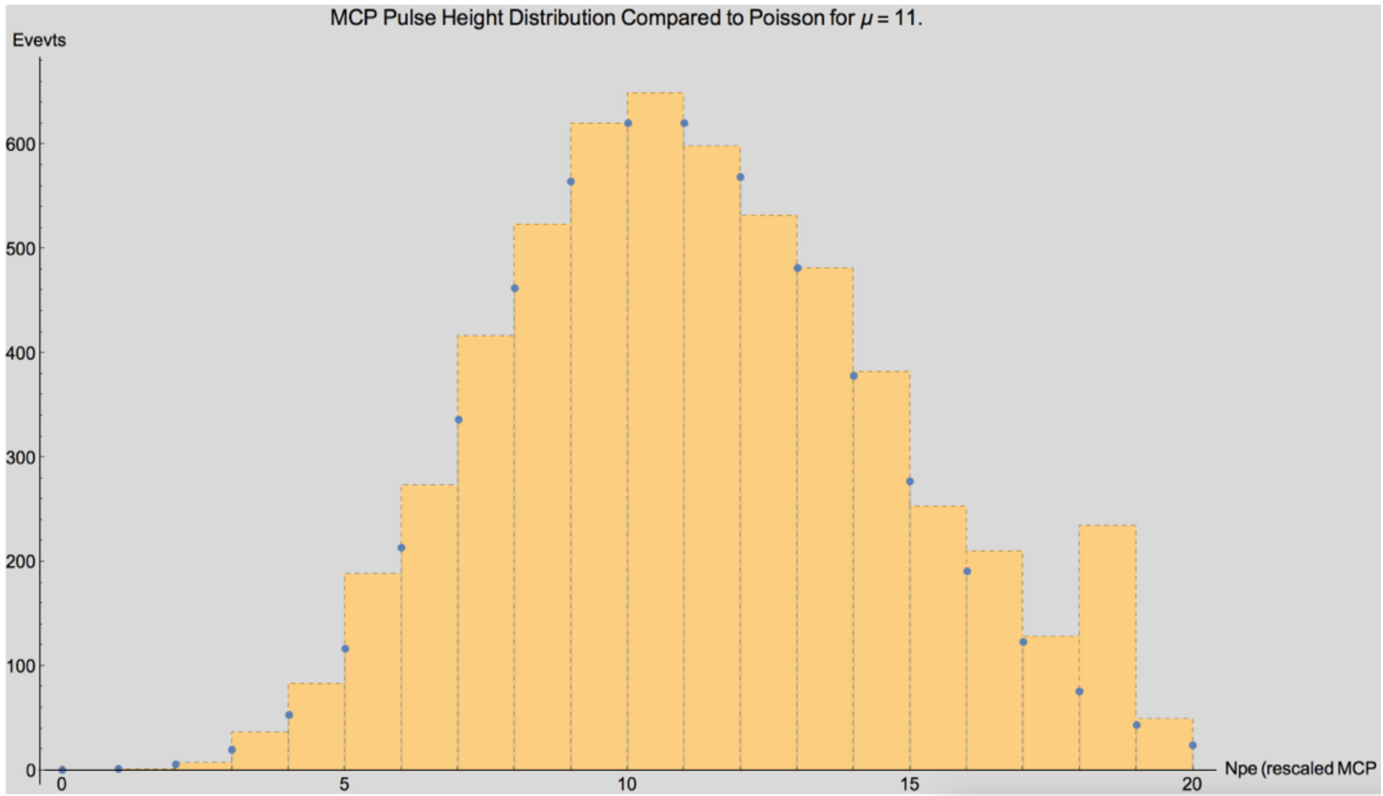
with Al photocatode and 5mm radiator almost fully efficient…



in CO2 we got (nicely shaped) signal…

->emphasis in preparation for August run:
-better gas quality by improved sealing of PICOSEC+recirculate
-several photo cathodes:CsI(11nm&18nm), Diamond, Cr
-different MgF2 radiator thicknesses
-start to explore new gases for reduce diffusion (ie Cf4+quencher..)
-2 different MMEGAS structures

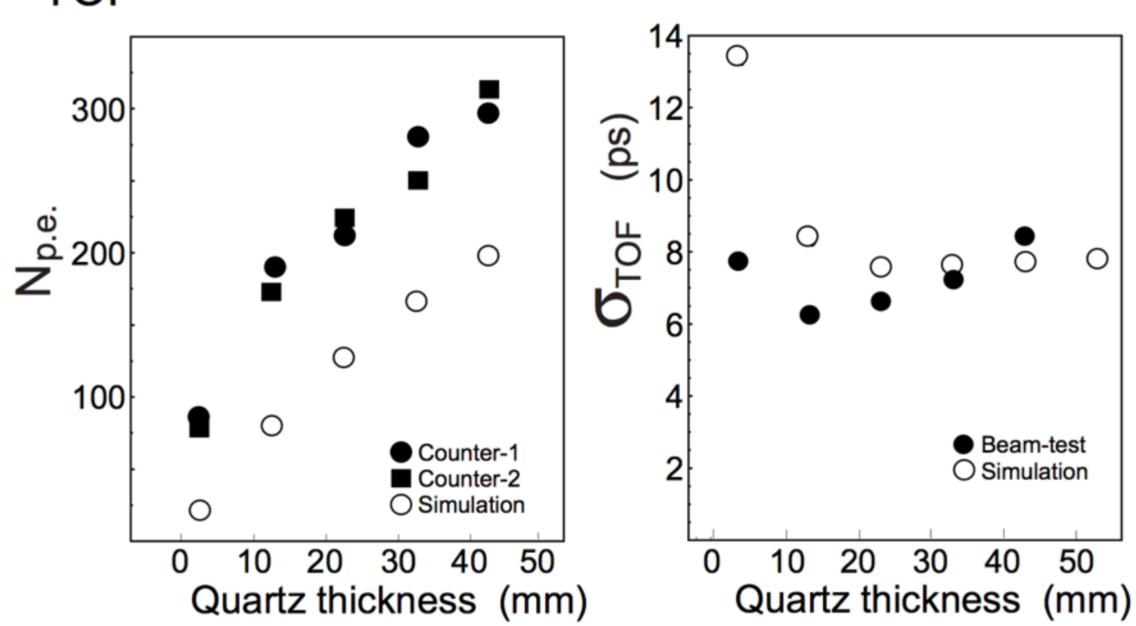
MCP (Hamamatsu R3809U-50&52):t0 reference



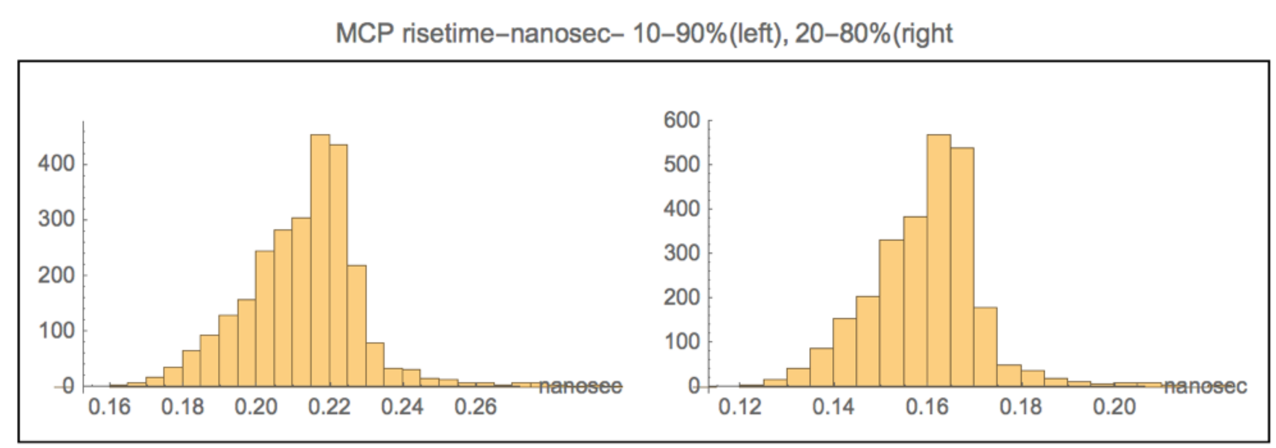
2 different MCPs
used for start counters

Similiarities to Inami et al

$N\gamma$, σ_{TOF} v.s. radiator thickness



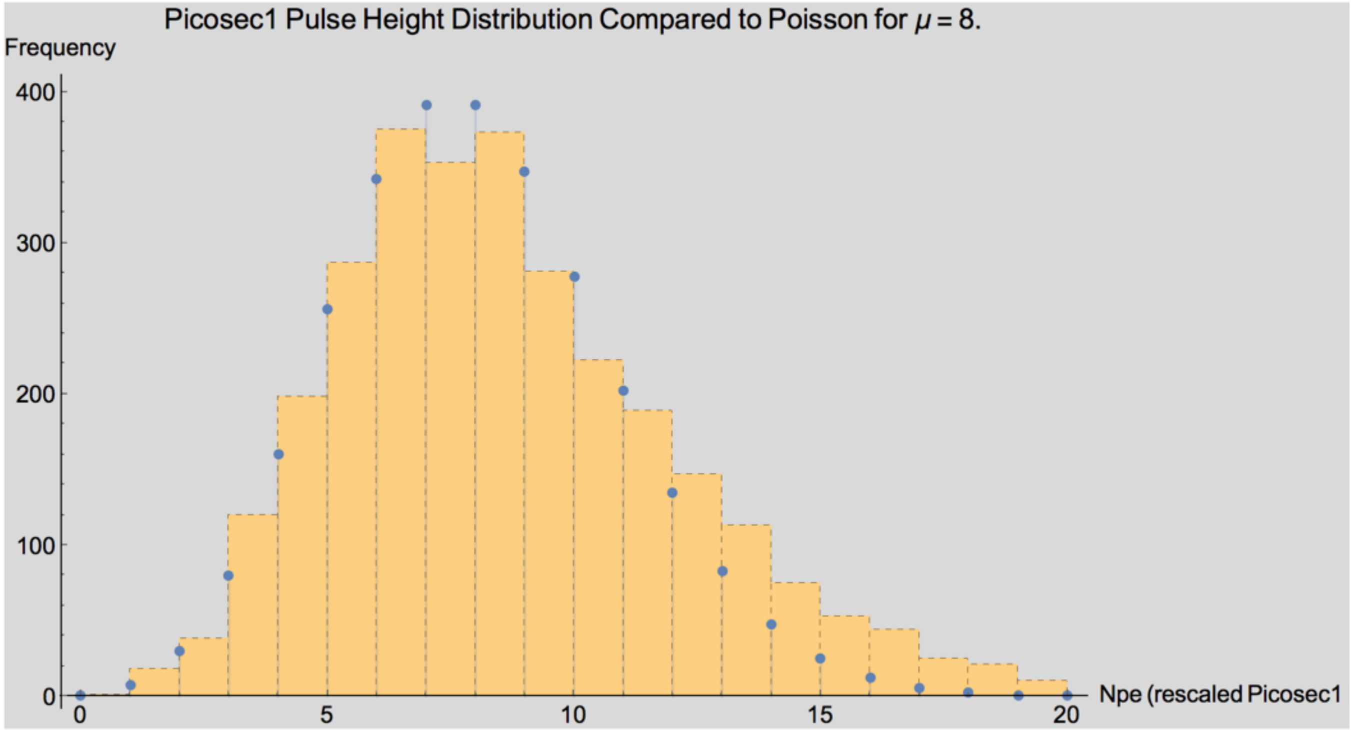
But also puzzles discussing with Henry, Va'vra et al…



First look at August data

- CsI photocathodes (11&18nm) on MgF2 windows made
- at Saclay, in CERN EP and Hamamatsu
- Diamond Photocathodes made @Saclay
- Metallic (Al, Cr..) made Saclay and CERN

- recall that Npe~10 a good result for timing
- best measurement will be from single pe data
- but Poisson statistics estimate reasonable

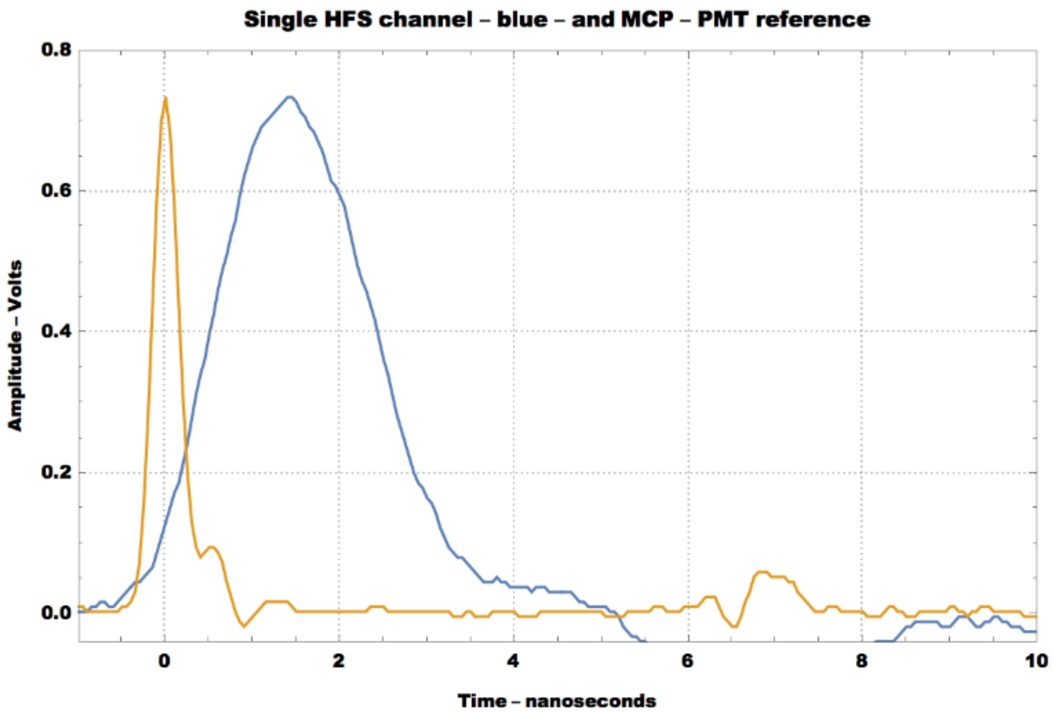


-> nice scaling w. window thickness

optimization of CsI layer

->significant timing improvement observed vs. June data

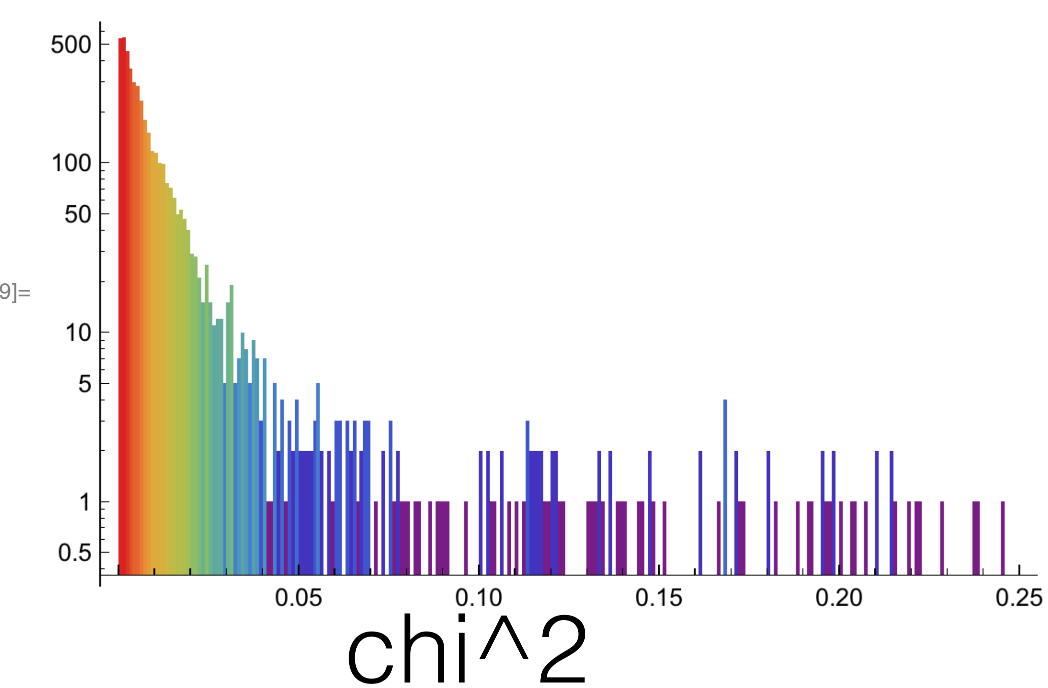
MCP and Silicon



~160 ps MCP risetime
~1 ns Si risetime, SNR~100:1
In what follows we show raw time difference.
Waveforms recorded using LRS 2.5 GHz scopes and SAMPIC waveform digitizer

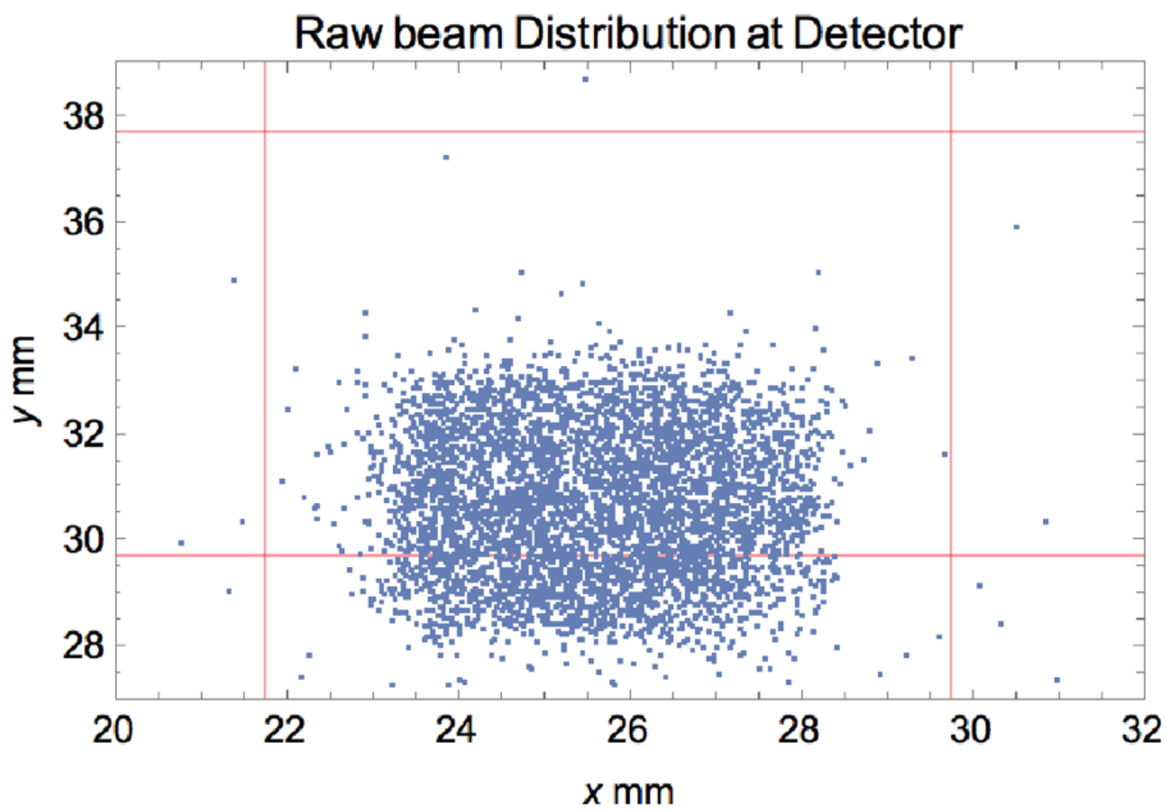
What's new in these data:

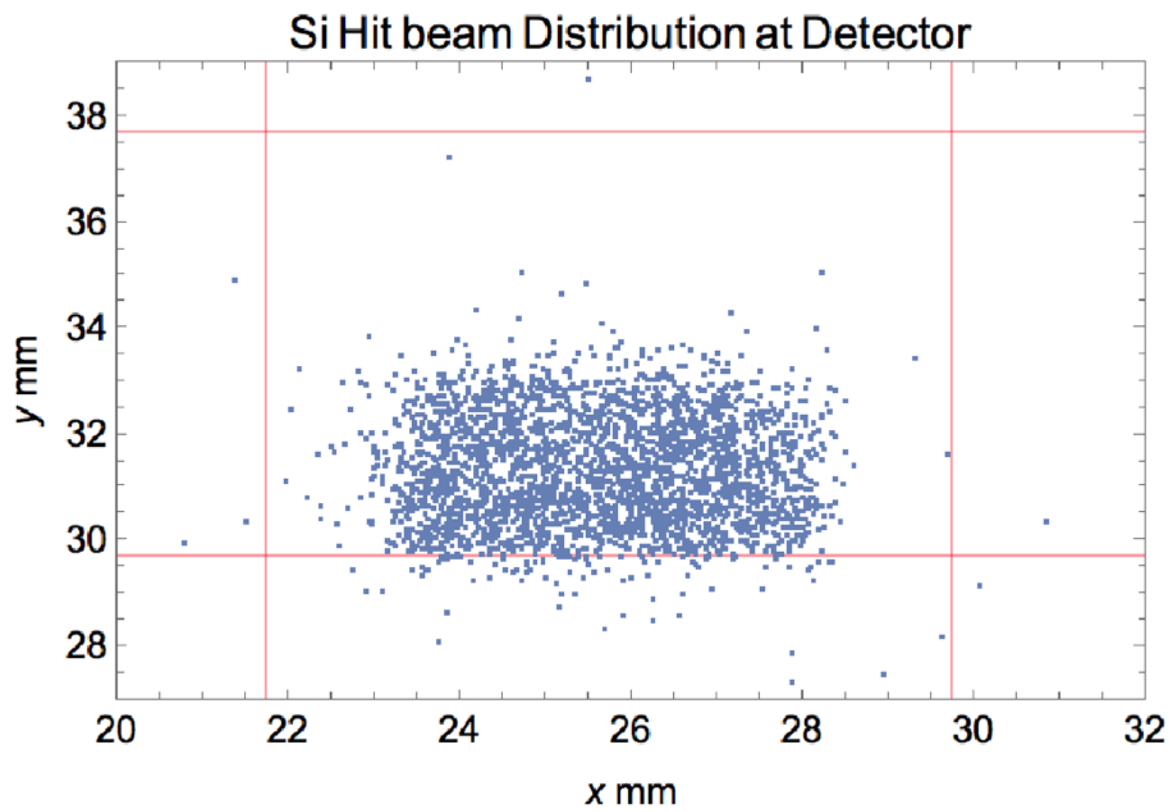
- continuing evolution of M. Newcomer HiBW SiGe transimpedence amp
- Having the MCPs has greatly simplified analysis



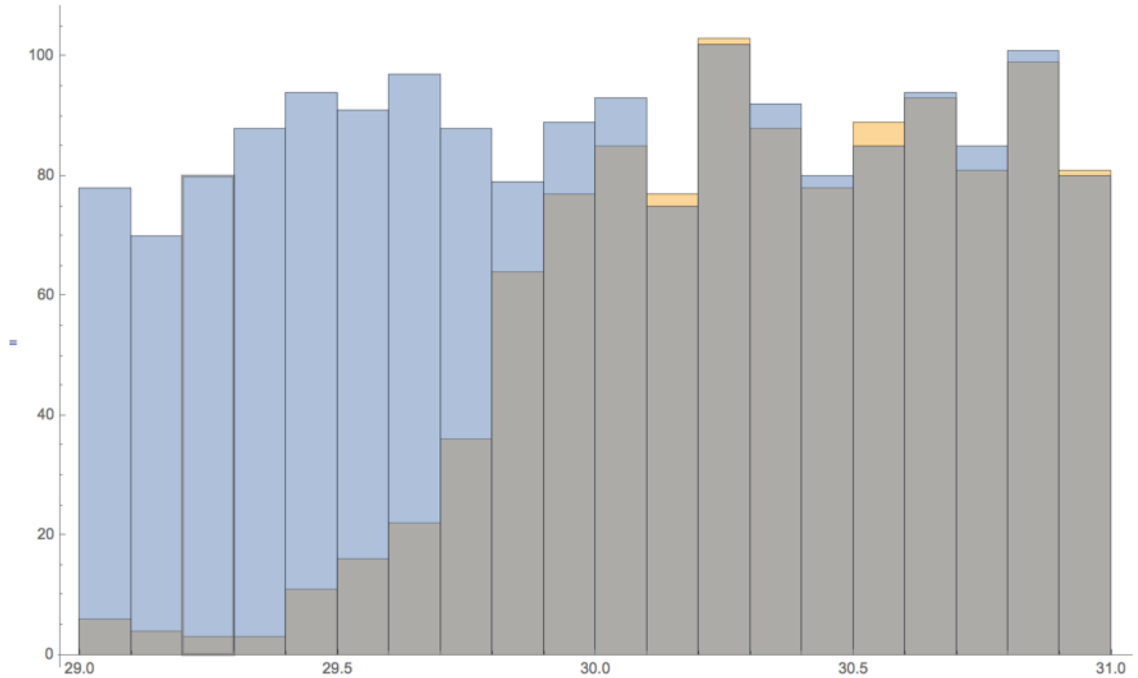
tracking tool->~ 40 micron rms

For first time detail HFS scanning to 0.1mm resolution of performance with beam!



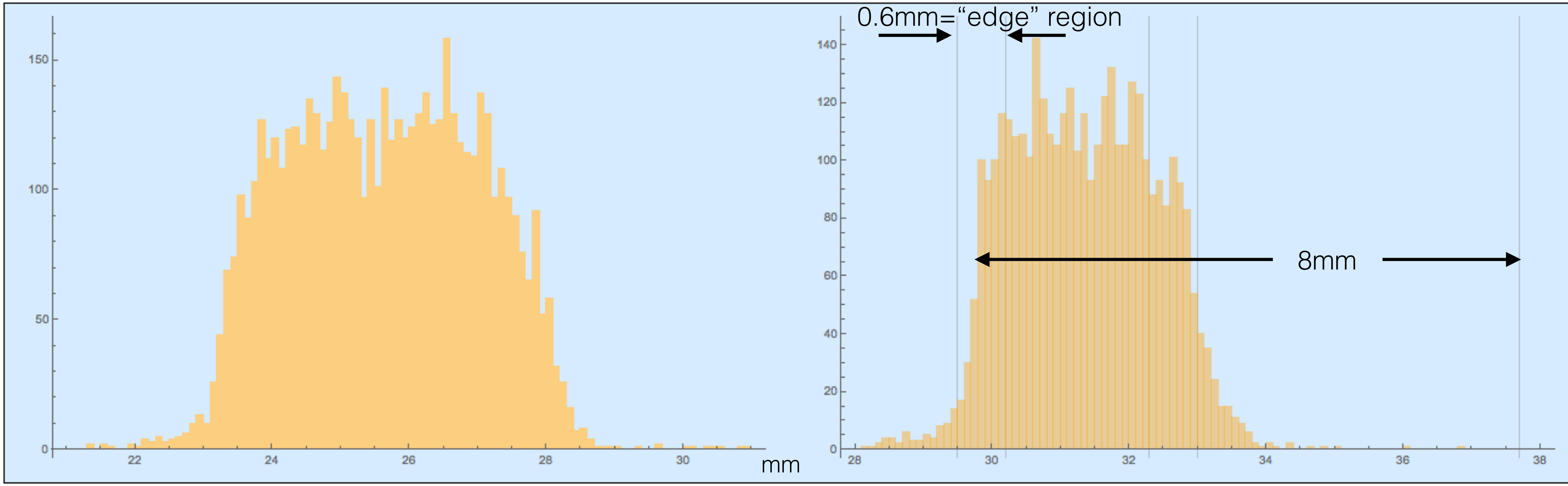


detailed y edge view->

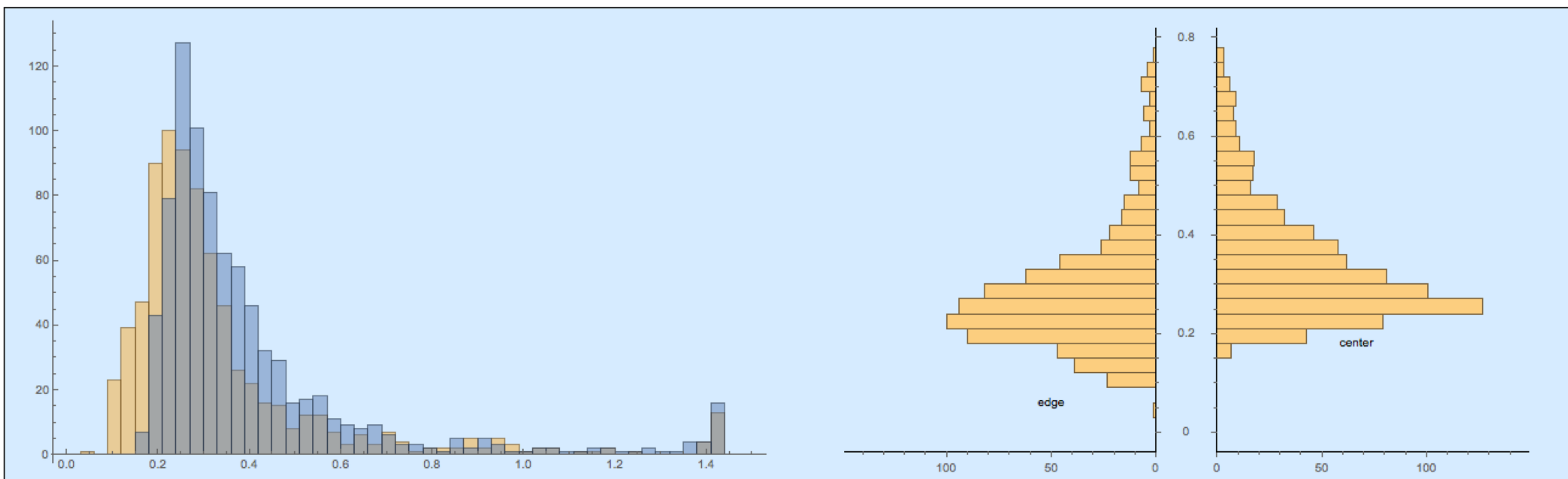


Response variation

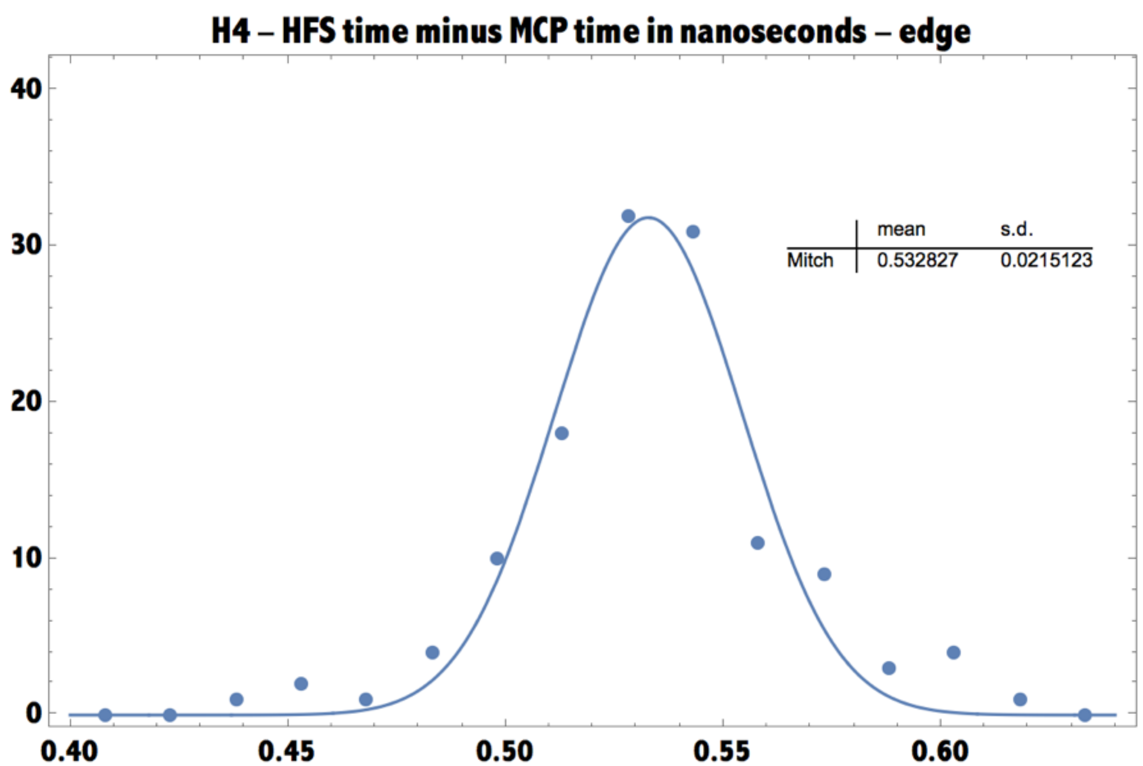
x ,y profile (in mm) of valid hits, Gridlines show selection for edge, center and top of Si

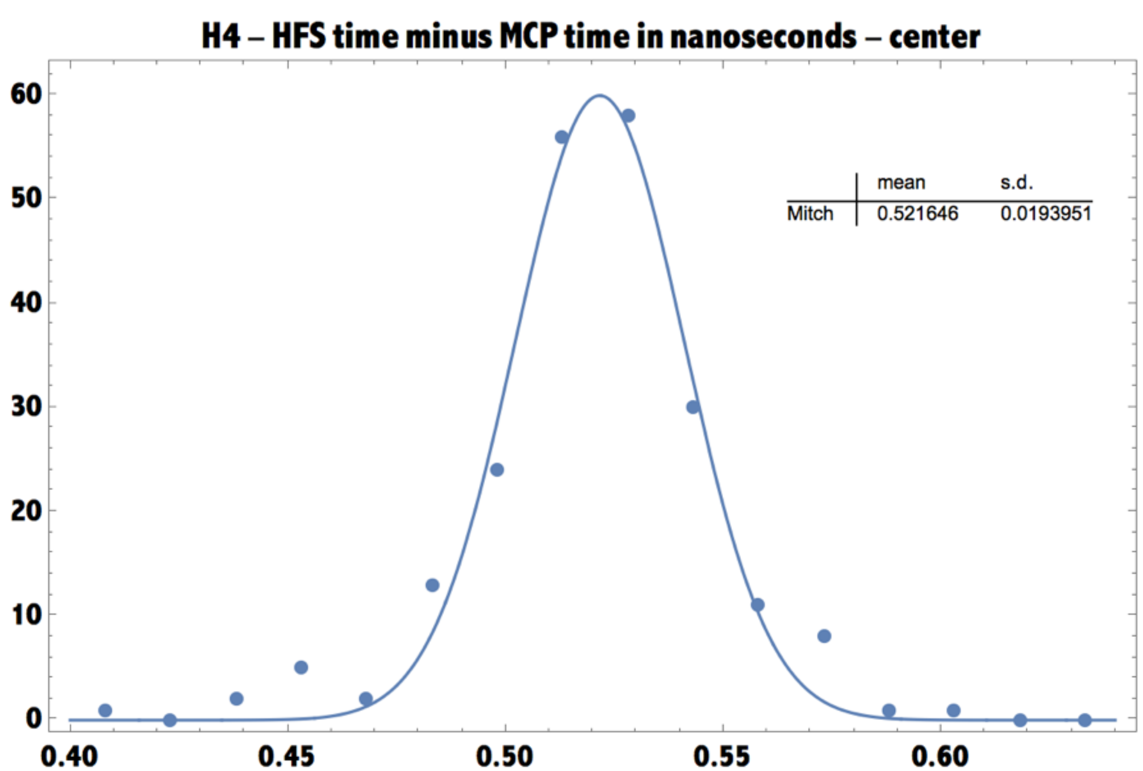


HFS Peak Amplitude in Volts, at detector edge compared w. center



very preliminary look at timing on detector edge





edge structure of these High field Si complicated. It has been difficult to evaluate w. laser model

first look at edge behavior very encouraging!

take small difference of edge behavior from bulk with grain of salt

timing algorithm preliminary small pulse height distortion

Plans:

- both projects have goal to achieve robust, ~20 picosecond technology w. “right-size” cells.
- these main objectives are being realized
- achieving robustness as well is critical
- for Si technology we just completed exposures to 10^{15}neq/cm^2
- for MMEGAS (and Hamamatsu) lifetime of photocathodes subject of intense study-> new metallic/diamond pc’s? Graphene or other methods to screen pc?
- similar issues as faced by MCP community
- + CMS related exercise started for large area timing layer in endcap
- continued ASIC development w. Mitch Newcomer

Further Reading

Michael Moll presentation at RD50 collaboration week June 6 , 2016 (Torino)

Sebastian White, Proceedings of the 2014 Workshop on Picosecond Photon Sensors for Physics and Medical Applications, Clermont Ferrand "R&D for a dedicated Fast Timing Layer in the CMS Endcap upgrade"
https://arxiv.org/abs/1409.1165

-RMD SBIR awarded May 2016
-Princeton DOE Advance Detector R&D Grant awarded June 2016

Sebastian White and Mitch Newcomer, at ACES 2014, CERN

Thomas Papaevangelou et al.,
"Fast Timing for High-Rate Environments with Micromegas" https://arxiv.org/abs/1601.00123

Sebastian White, Proceedings of CHEF 2103 ,Paris.
"Experimental Challenges of the European Strategy for Particle Physics" https://arxiv.org/abs/1309.7985

Sebastian White et al., "Design of a 10 picosecond Time of Flight Detector using Avalanche Photodiodes"
https://arxiv.org/abs/0901.2530

Sebastian White, "On the correlation of sub-events in ATLAS and CMS/TOTEM Experiments", 2007
https://arxiv.org/abs/0707.1500